TECHNICAL MEMORANDUM

NO. 10

UTILIZATION AND EVALUATION OF VEGETATIVE INDICES
FOR CROP CONDITION ASSESSMENT

CROP CONDITION ASSESSMENT DIVISION

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREIGN AGRICULTURAL SERVICE

HOUSTON, TEXAS

SEP 26 1979

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Approved by:

Jimmy D. Murphy
Director, Crop Condition Assessment Division

1 REASON FOR ISSUANCE

To document and evaluate how vegetative indices of Landsat data have been used to depict crop conditions relating to the production of wheat.

2 COVERAGE

The results of this report will be used to assess present and future crop condition techniques for analyzing crop conditions in foreign countries by the Crop Condition Assessment Division.

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Larry L. Davis - FAS, CCAD

18 Sept 79
Date

UTILIZATION AND EVALUATION OF VEGETATIVE INDICES FOR CROP CONDITION ASSESSMENT

PART 1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this report is to document CCAD investigations and findings in the use of vegetative indices for evaluating crop conditions, specifically wheat.

1.2 SCOPE

The scope of this report is primarily confined to the use of unsupervised vegetative indices. Unsupervised vegetative indices are calculated automatically and do not require analysts to isolate different types of vegetation for which separate indices are calculated. Supervised indices will be discussed only to gain a better understanding of automated unsupervised indices.

1.3 BACKGROUND

The Crop Condition Assessment Division (CCAD) provides the Foreign Agricultural Service (FAS) with crop condition assessments for crops and countries of particular economic interest to the United States. The CCAD was officially established in February 1979 within Commodity Programs of the FAS. Its establishment was in response to information requirements stated by Secretary of Agriculture Bergland in February 1978. Early warning and crop condition assessment is the requirement for which the CCAD responds.

During the years preceding the establishment of the CCAD, USDA personnel participated in the LACIE. The LACIE provided initial techniques to assess crop condition. These techniques were offshoots of techniques used to estimate wheat production. The LACIE used visual and digital analysis of Landsat imagery during crop year 1976 to monitor drought conditions in the U.S. Great Plains. The visual analysis defined the areal extent and subjective severity of the drought by assessing the amount of red, which relates to the amount of vegetative biomass, in the image scene. The digital analysis attempted to quantify this subjective visual analysis. The procedure known as the Green Index Number (GIN) was developed using a mathematical transformation of digital Landsat data. The basic transformation, developed by the Environmental Research Institute of Michigan (ERIM), gives a numerical value relating to vegetative greenness. A value was calculated for each LACIE Landsat image, and the values assessed against an expected baseline for the wheat growing season.

In 1978 and 1979 the CCAD calculated the GIN, as well as seven other vegetative indices (Appendix A) for selected areas of the USSR, Canada, U.S. and Australia. The various indices were calculated to determine if others were superior to the LACIE GIN for crop condition assessment. The CCAD evaluated these indices and found that all measure greenness and relate to yield in a similar manner (Exhibit 1, A and B). The Ashburn Vegetative Index (AVI), developed by the USDA, and the GIN have been primary indices for CCAD crop condition assessments.

PART 2.0 CROP CONDITION ASSESSMENT

2.1 VEGETATIVE INDICES

The two indices in this study are the AVI and the GIN. The AVI is simple and is derived from the Landsat channels relating to chlorophyll absorption (Channel 2) and infrared reflectance (Channel 4). An AVI for each pixel is derived by calculating 2(Ch4)-Ch2. The average AVI is an average value of all pixels with individual AVI values above zero. When Landsat 3 data are used, they are calibrated to Landsat 2 by the following multipliers: 1.161 (Ch 1), 1.230 (Ch 2), 1.246 (Ch3), and 1.062 (Ch 4). Haze and sun angle corrections were not used prior to the calculation of the AVI and GIN indices.

The GIN is very different because it is a percentage, rather than an average, of pixels with a value above a threshold of 15. Theoretically, everything above 15 is indicative of full vegetative growth. The GIN is a product of all four Landsat channels and is derived from the Kauth greenness channel. The GIN is the percent good pixels above a Kauth greenness of 15 in addition to a soil line value. Kauth greenness is the sum of (.603 X Ch 1)+(-.660 X Ch 2)+(.428 X Ch 3)+(.131 X Ch4). The soil line value is that greenness value below which 1 percent of the good pixels fall. Good pixels are determined by a screening algorithm that identifies bad pixels which are clouds, cloud shadows, water, and garble. As with the AVI, Landsat 3 data are calibrated to Landsat 2 data prior to all calculations.

2.1.1 Utilization of Indices for Crop Condition Assessment. The indices in crop condition assessment are used during the growing season to determine the condition of crops at 18-day intervals. North Dakota will be used as an example to illustrate its use. During 1978, 93 LACIE segments in North Dakota were acquired and indices calculated. The indices were geographically plotted by a line printer to a specified map base. Figures 1 and 2 are AVI and GIN plots, respectively. Each plotted number represents a LACIE segment acquisition at the wheat growth stage shown in Figure 3. Growth stages have been derived from a CCEA (Center for Climatic and Environmental Assessment) model run on data from eight weather stations in the state and spread to the segment locations. The printed stages correlate to the actual overpass date of the Landsat. Wheat growth stages are:

1.0	=	50% Planted
2.0	=	50% Emerged
3.0	=	50% Jointed
4.0	=	50% Headed
5.0	=	50% Soft Dough
6.0	=	50% Ripe

Without regard to previous data, initial analysis of these plots involves the growth stage of the crop and the intensity of plotted index values. In early June the crop for the state is about 50 percent jointed except for the southwest corner which is near 50

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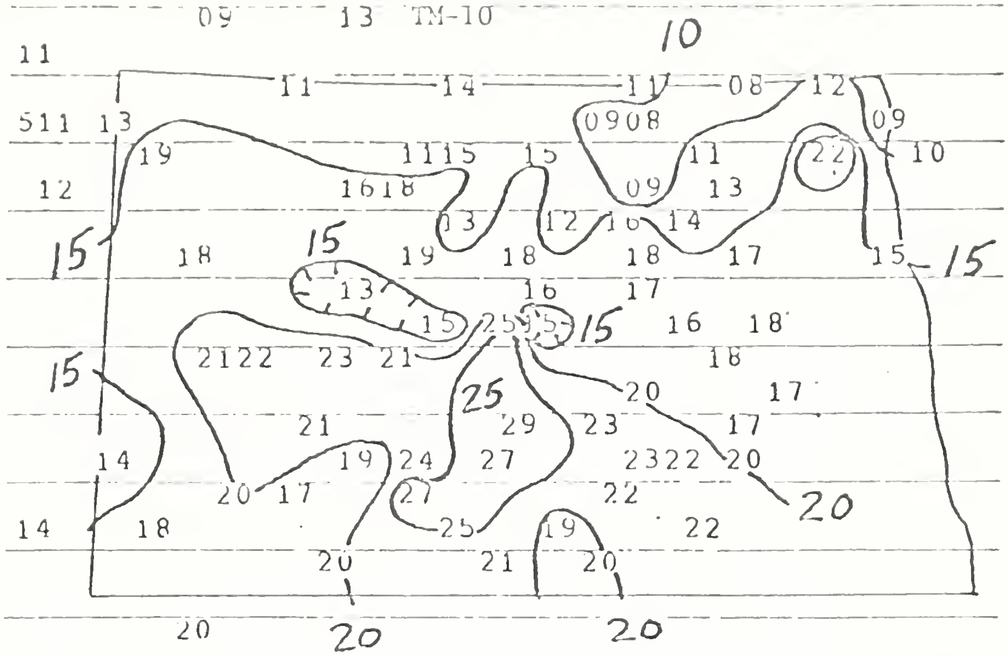

FIGURE 1
AVI
June 1 - 6, 1978

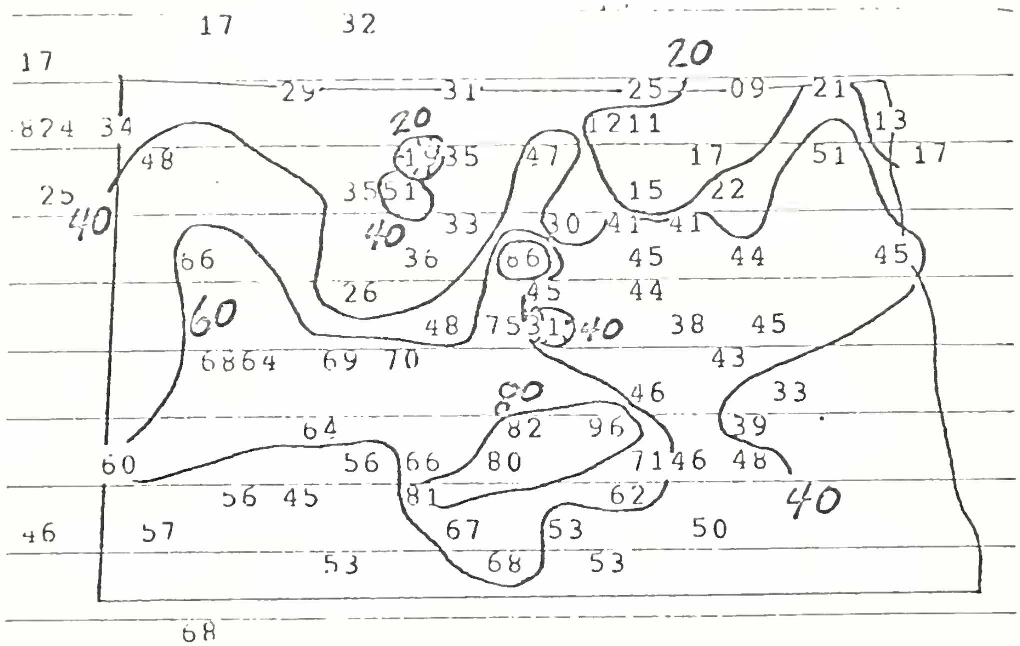

FIGURE 2
GIN
June 1 - 6, 1978

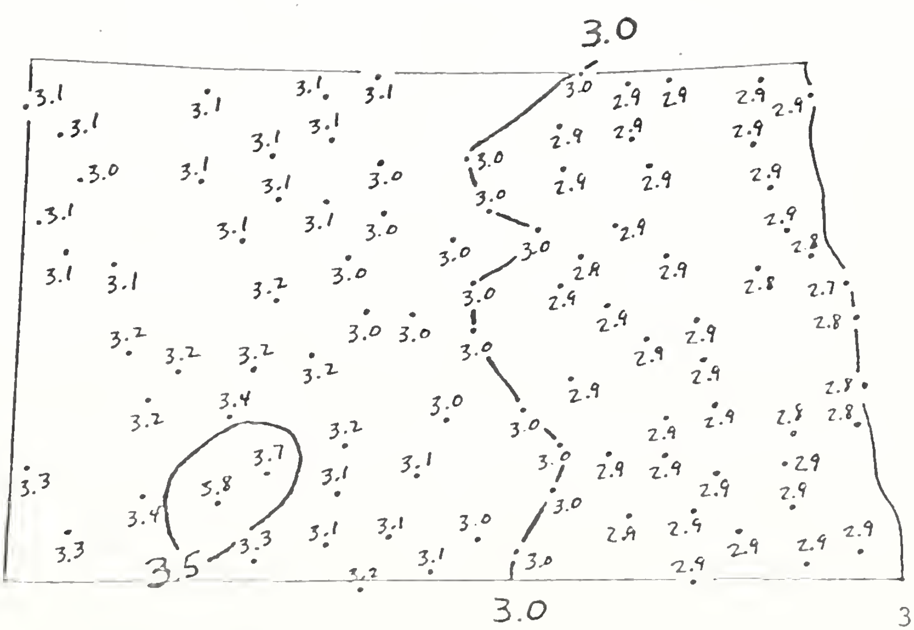

FIGURE 3
Crop Calendar
June 1 - 6, 1978

percent headed. Assuming that each index value equally represents its respective location relative to crop condition, both AVI and both GIN plotted data are isolined. Also, the assumption is made that higher index numbers relate to better conditions. An analysis of the AVI plot for June 1-6, 1978, indicates the best conditions to be in the south-central part of the state. The poorest conditions* conclusion. Drawing isolines is always difficult but even more so when data are missing due to clouds. The southeast corners of Figures 1 and 2 are without data due to clouds from the trailing edge of an eastward moving cold front. The satellite acquires data from east to west. Therefore, the right side of the state is covered on June 1 while the left side is covered on June 6.

Figures 4-6 show the situation on July 7-12, 1978. The state should be higher for most of the state than in June. Indices in the southwest corner where the crop is maturing have begun dropping slightly. The AVI plot shows a high ridge of indices extending from the north-central towards the east-central part of the state. Lower values, suggesting poorer conditions, are present in the northeast and in the west. The GIN and the AVI plots appear different but the same basic information is apparent. Isoline intervals may be a large contributing factor for the difference in appearance.

Since GIN values are higher than AVI values, an isoline interval of 20 was chosen for GIN plot while an interval of 5 was chosen for the AVI plot.

2.1.2 Evaluation of Indices for Crop Condition Assessment. Two assumptions were made earlier about isolines and the interpretation of isoline plots. First it was assumed that each index value equally represents its geographic location. For example, an index of 25 for one segment equates to a 25 for another segment at the same growth stage. The second assumption was that higher indices relate to better conditions at the same growth stage. The first assumption will be evaluated in Section 2.1.3, Vegetative Index Profiles. The second assumption concerning crop condition will be discussed in this section.

To evaluate the indices for crop condition assessment, a numerical measure relating to crop condition must be obtained. Ground truth data concerning the amount of plant biomass may be collected and related to the indices. However, this was not available, and it may not necessarily relate to crop condition. Yield is the result of crop condition over the entire growth cycle of the plant. Potential yield of the crop will vary during the season depending on positive and negative environmental factors. The assessment indices for crop condition at 18-day intervals during the season relates to potential yield at that period of time, but the assessment can only be evaluated against final yield. Ground truth of potential yields is not available for evaluation.

*INSERT
exist along the northern border. The GIN plot indicates the same

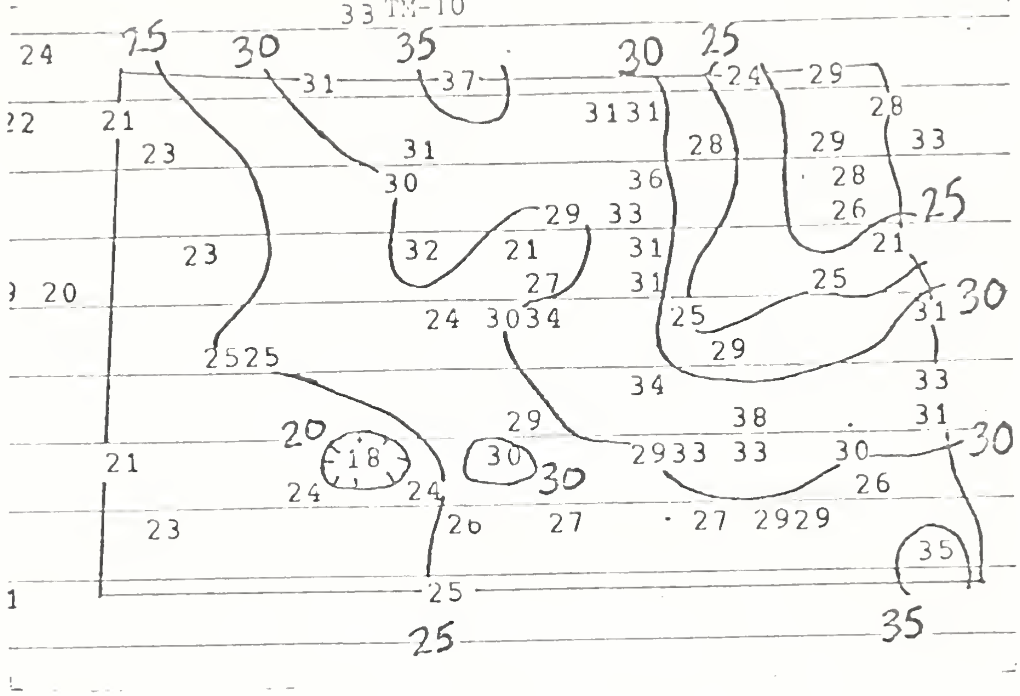

FIGURE 4
AVI
July 7 - 12, 1978

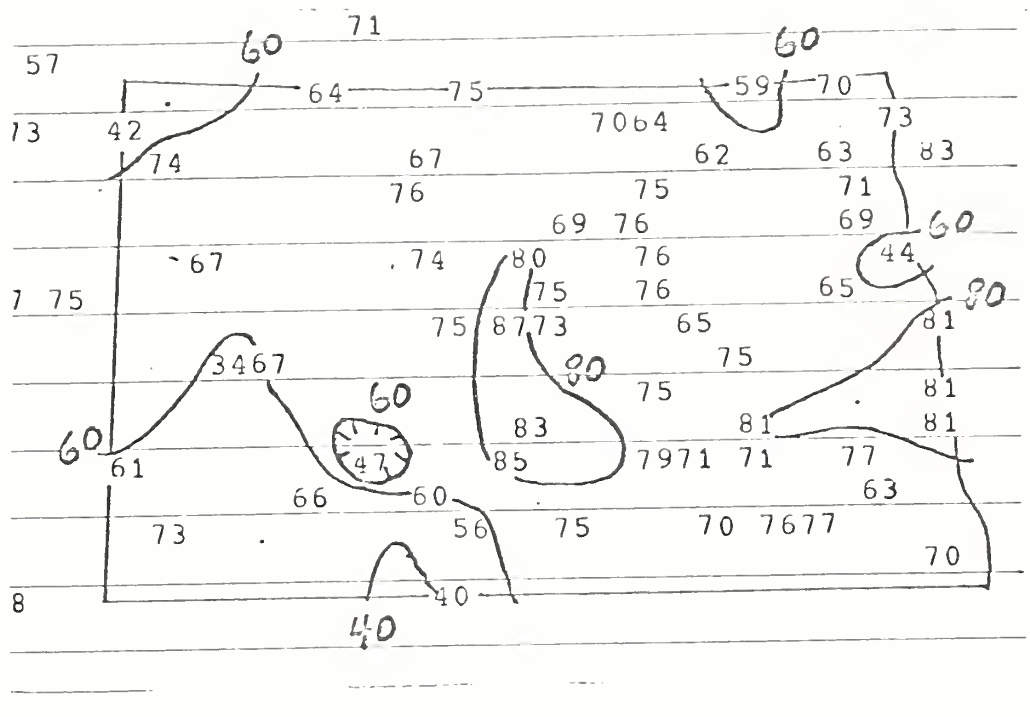

FIGURE 5
GIN
July 7 - 12, 1978

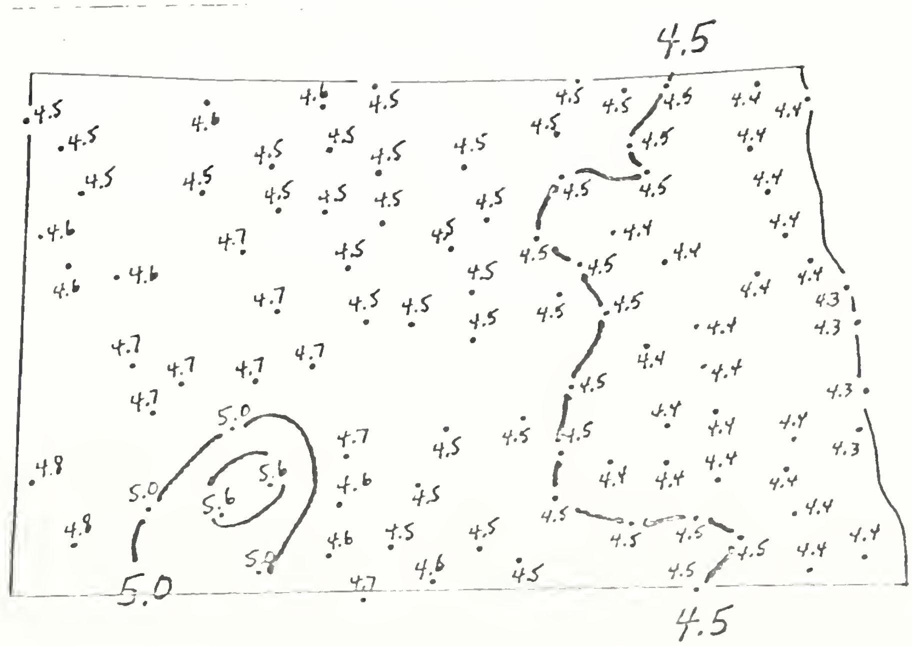

FIGURE 6
Crop Calendar
July 7 - 12, 1978

Figures 7 and 8 (AVI and GIN) are the same as Figures 1 and 2 but are redisplayed with Figure 9 to show the relationship of the indices of final 1978 county yields. The final yields were determined by the Statistical Reporting Service of the Economics, Statistics, and Coopertives Service (ESCS). The county yields for the state have been isolined using a five-bushel interval. Although individual index numbers may not relate to final county yields, they should follow a trend whereby higher indices relate to higher yields. Initial analysis suggested that on June 1-6, 1978, crop conditions were better in the south-central part than in the northern part of the state. Isolines of final yields do not support this assessment.

Figures 10 and 11 (AVI and GIN) are also the same as Figures 4 and 5, and Figure 12 is the isolines of wheat yield. The initial assessment of crop condition on July 7-12, 1978, was that crop conditions were best in an area extending from the north-central part to the east-central part of the state. Conditions were not as good in the northeast and western parts of the state. This assessment is not supported by the isoline map of county yields. Differences in wheat growth stages across the state no doubt contribute to problems with accurately assessing state-wide plotted index data. Additional problems are related to the equal treatment of index values at different locations. The problem with equal treatment is addressed in Section 2.1.3, Vegetative Index Profiles.

2.1.3 Vegetative Index Profiles.

2.1.3.1 Unsupervised Indices. Unsupervised indices (all vegetation in the scene) have been used primarily in CCAD operations due to the ease of their automation. Individual segment profiles allow for a better understanding of each plotted value as well as the total plotted map. Figure 13 is a profile of Segment 1612 in McHenry County, North Dakota. The graph shows both AVI and GIN values against time for 1977 and 1978. Both indices show early season green-up and late season maturing of vegetation. The GIN is the percent pixels above a green number of 15; and as springtime arrives, the profile rises rapidly. The AVI is an average index and is less prone to extreme movements. The GIN profile in Figure 13 is greatly influenced by the percent non-agriculture in the scene. Since the segment is 85 percent non-agriculture, the GIN values increase much faster than the AVI as springtime arrives. Little can be said about the intensity of vegetative greenness represented by the GIN other than that all pixels in the percentage are above a green number of 15. For instance, a GIN of 94 in early June 1977 could mean that all 94 percent of the pixels in the scene had green numbers of 16 or that all had green numbers of 50. Only one level of green intensity is measured. However, the AVI is an average of all green pixels and as a result has many levels of intensity.

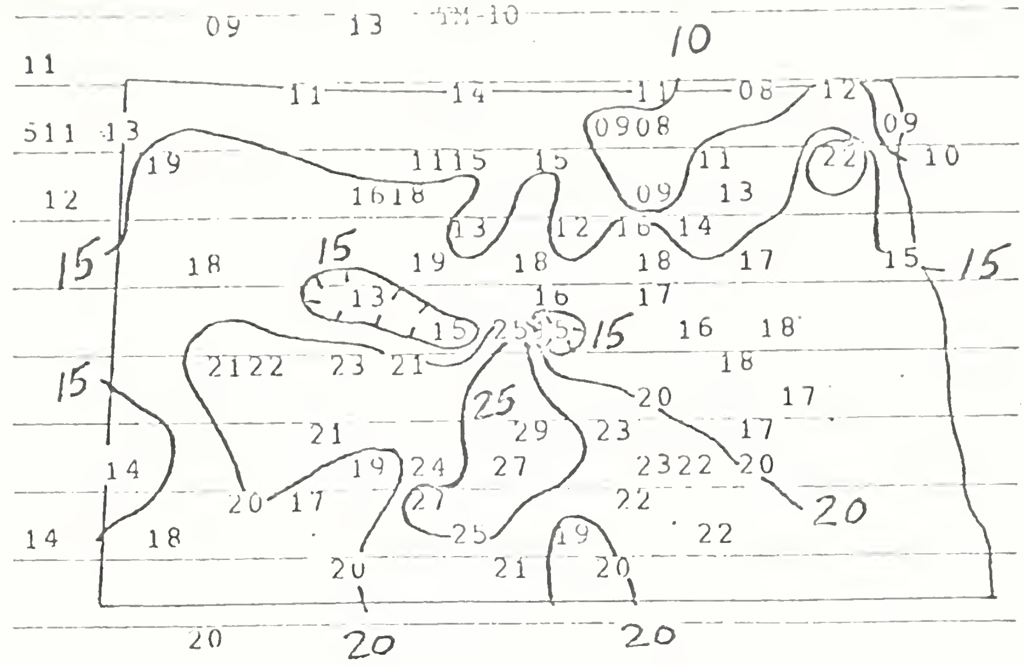

FIGURE 7
AVI
June 1-6, 1978

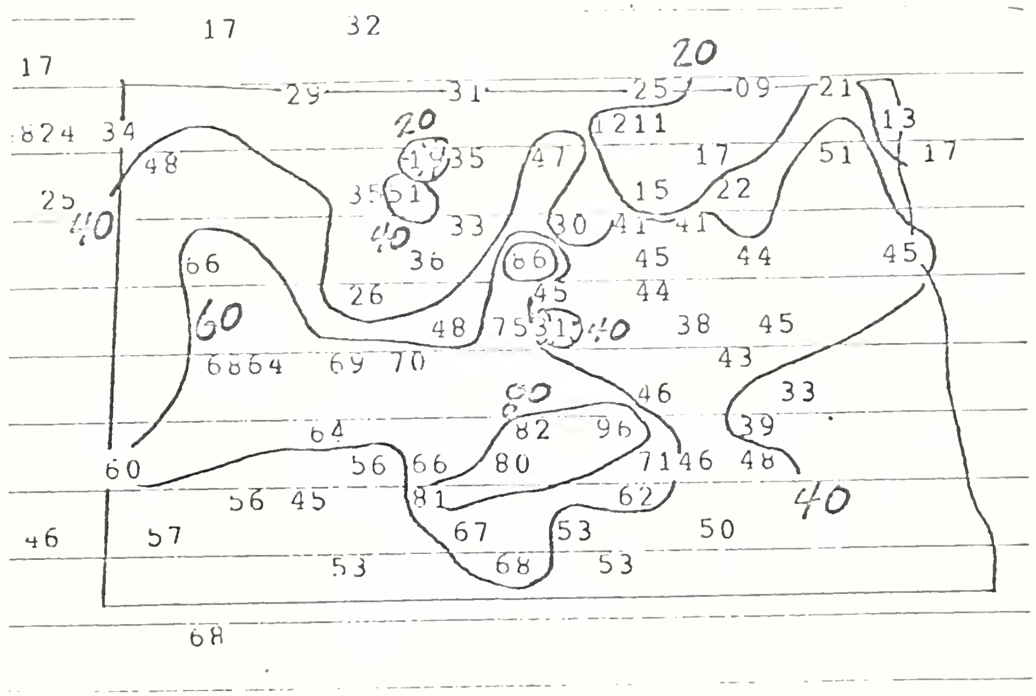

FIGURE 8
GIN
June 1-6, 1978

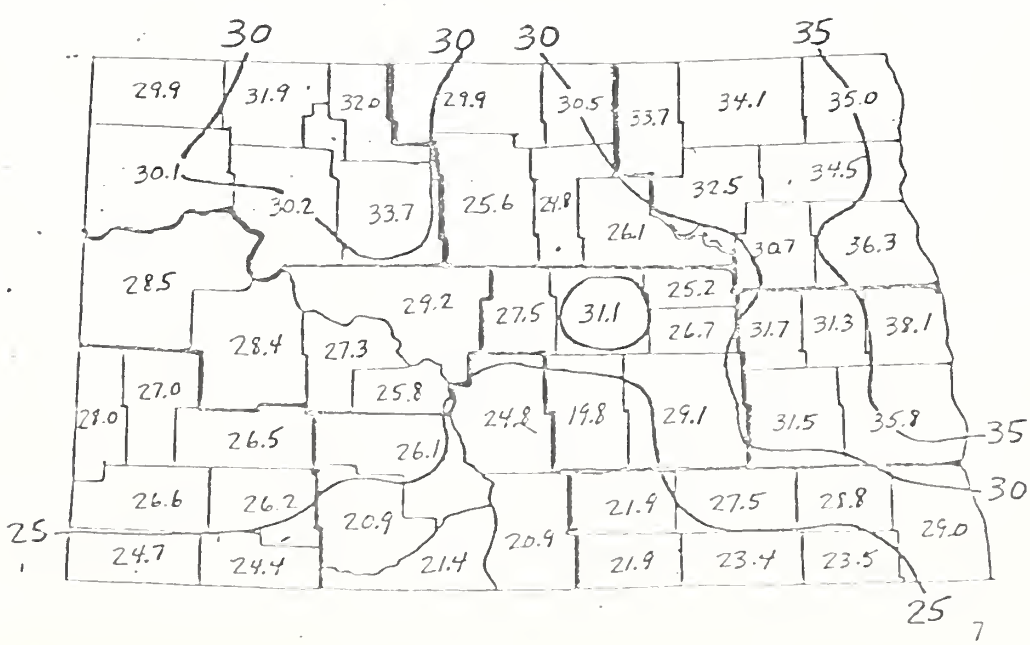

FIGURE 9
1978 SRS
Wheat Yields

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FIGURE 10
AVI
July 7-12, 1978

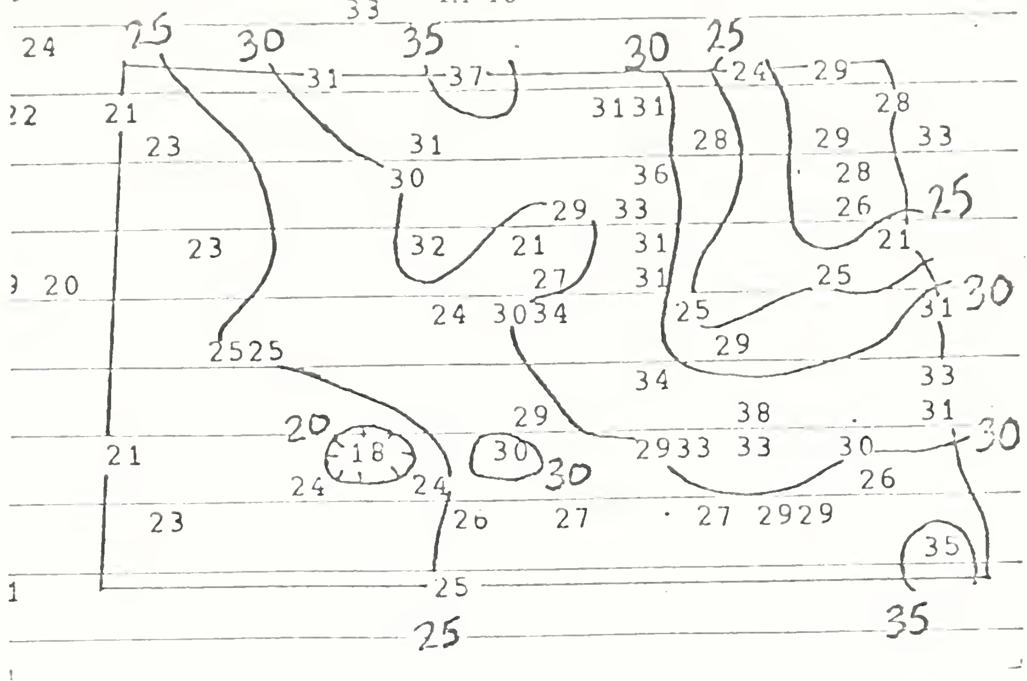


FIGURE 11
GIN
July 7-12, 1978

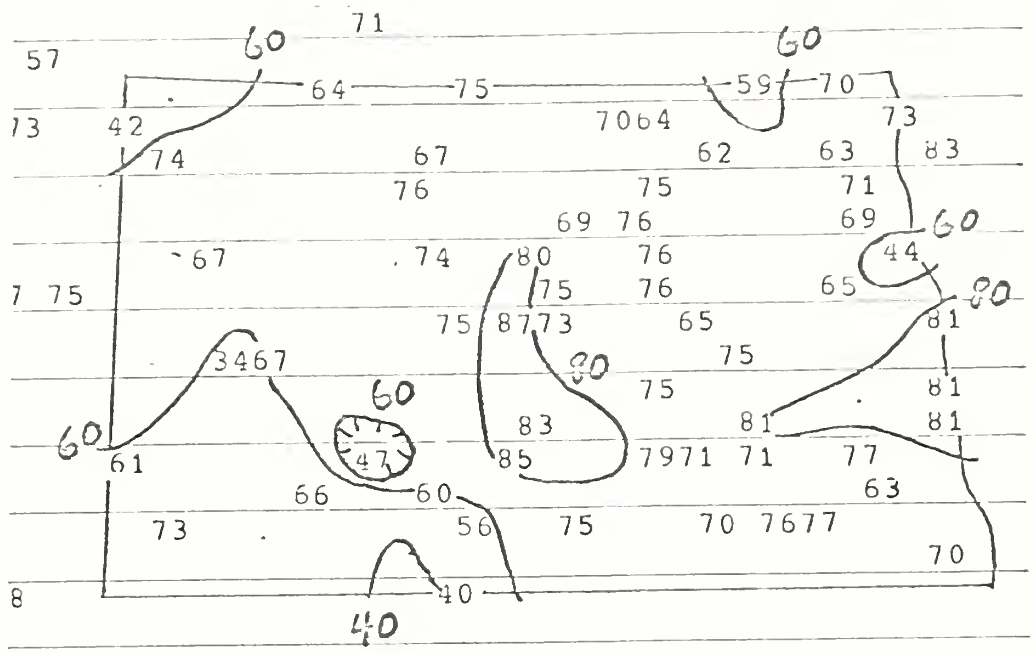
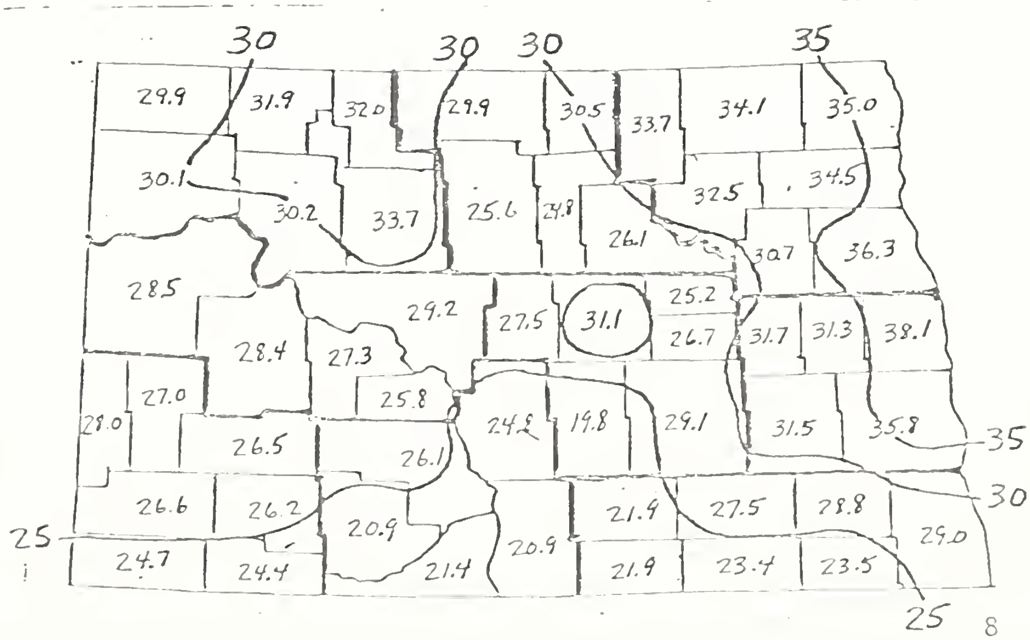


FIGURE 12
1978 SRS
Wheat Yields



SEP 26 1979

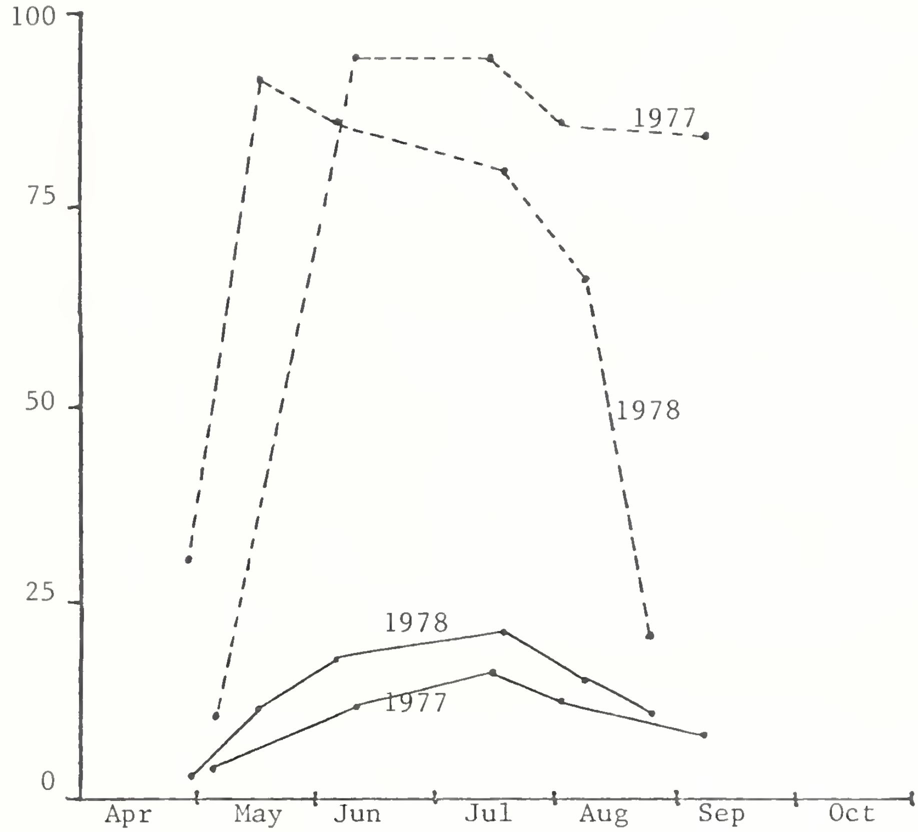


FIGURE 13
Segment 1612
15% Agriculture
5% Spring small grains
1977 County yield 17.7 bu
1978 County yield 27.3 bu

—— AVI
- - - - GIN

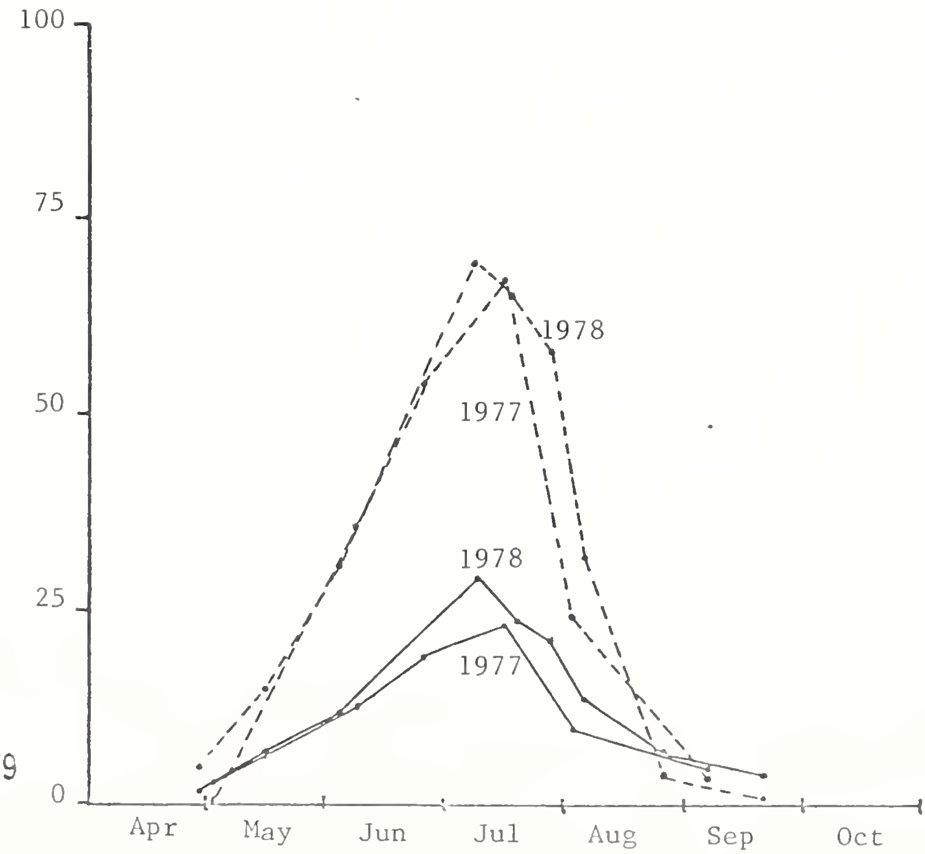


FIGURE 14
Segment 1461
80% Agriculture
40% Spring small grains
1977 County yield 15.2 bu
1978 County yield 24.6 bu

—— AVI
- - - - GIN

Both indices are unsupervised and are both influenced by the uniqueness of the area for which they represent. Most important are the influences of non-agriculture and multiple crops in the scene. Both can severely distort unsupervised indices and make interpretation difficult. While natural vegetation contributes to high GIN values, it tends to reduce the average AVI thereby leading to a flat vegetative profile. Indices are not expected to correlate highly to county yields but should indicate crop condition or yield trend. For Segment 1612, GIN indicates that 1977 was a better crop year than 1978, while the AVI indicates the opposite. County yields tend to support the AVI.

Segment 1461 (Figure 14) is different from Segment 1612 because it is 80 percent agriculture and normally contains 40 percent spring small grains. The GIN and AVI profiles are more alike in this segment than in Segment 1612 because the contour of the vegetative profiles are more influenced by spring small grains than by natural vegetation. Both indices gradually rise and rapidly fall as the grains mature because of little competition from natural vegetation or summer crops (mono-cropped area) that might influence the vegetative profiles. Both the GIN and AVI seem to indicate that 1978 was a better year than 1977; although, the AVI seems more indicative.

The vegetative profile of Segment 1606 (Figure 15) is similar to that of Segment 1461 even though less small grains influence the total profile. Both the GIN and AVI plots show vegetation in the scene peaking in 1978 slightly after 1977. This would indicate that the 1978 crop is slightly behind and maturing later than the 1977 crop. Both the GIN and AVI profiles indicate that the 1978 crop year was slightly better than 1977. The 1978 GIN profile bounces back and forth in August and September while the 1978 AVI profile levels off. This phenomenon is probably related to the greening of vegetation caused by occurrences of precipitation.

Figure 16 is a composite plot of Segments 1461, 1612 and 1467 for crop year 1977. The GIN plot shows Segment 1612 to be better than the other two segments, while the AVI plot shows it to be worse than the other two segments. The presence of 85 percent non-agriculture (natural vegetation) in Segment 1612 distorts both the AVI and GIN indices relative to the indices of the other two segments and therefore leads to erroneous conclusions. The profile of Segment 1612 is flatter than the other two segments and does not drop as rapidly when grains mature. Segments 1461 and 1467 are comparable since both contain approximately the same percentage agriculture and spring small grains. The AVI plot definitely indicates Segment 1467 to be in better condition than Segment 1461. The county yield where 1467 is located was 37.1 bushels as compared to 15.2 bushels for the county where 1461 is located. GIN does not show any significant difference between Segments 1461 and 1467.

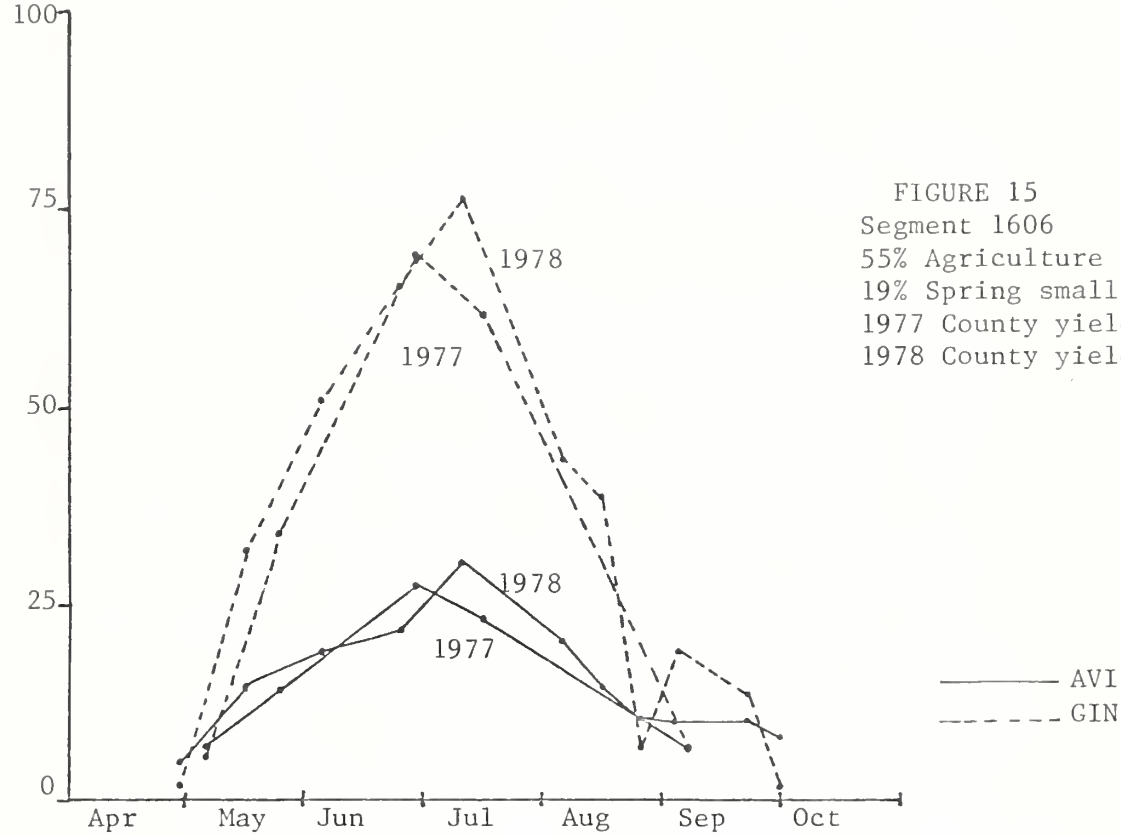


FIGURE 15
Segment 1606
55% Agriculture
19% Spring small grains
1977 County yield - 25.8 bu
1978 County yield - 34.7 bu

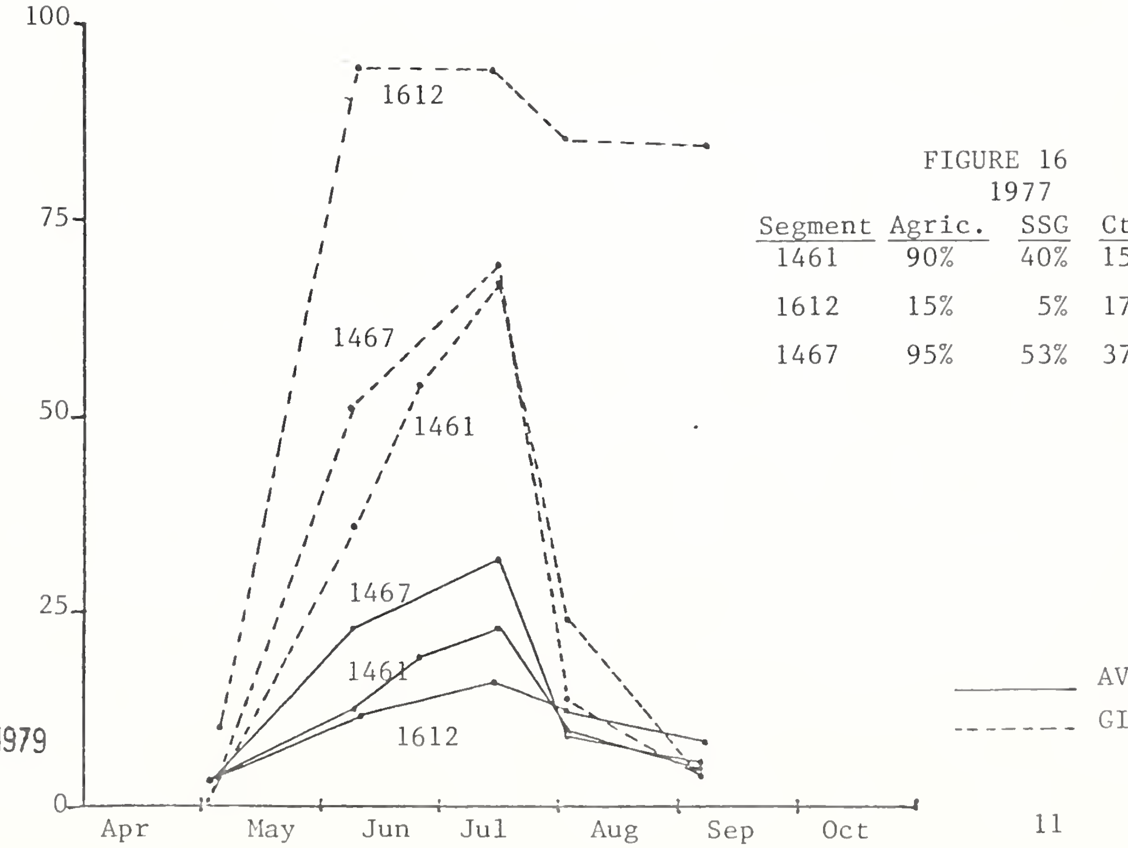


FIGURE 16
1977

Segment	Agric.	SSG	Cty Yld.
1461	90%	40%	15.2 bu
1612	15%	5%	17.7 bu
1467	95%	53%	37.1 bu

2.1.3.2 Supervised Indices. Supervised indices represent specific vegetation rather than all vegetation in an image scene. Supervised indices require the crop to be isolated through clustering, classification, masking or field definition. The requirements for crop isolation prevent the supervised technique from being anything but semi-automatic in operation. Indices derived from supervised techniques are easier to analyze and interpret than unsupervised indices. Vegetation that would distort a particular index is simply excluded from the calculation.

Figure 17 displays unsupervised AVI indices relative to supervised indices representing natural vegetation and small grains. The natural vegetation is greener than the small grains early in the season. As the season progresses, the small grains become greener than the natural vegetation, but by the end of the season the small grains are not as green as the natural vegetation. The unsupervised profile representing all vegetation seems to fall between the natural vegetation and small grain profiles. Emerging grains in the spring, natural vegetation in mid-season and maturing grains in the fall moderate and decrease the unsupervised profile. The rise of the natural vegetative profile and the leveling off of the all-vegetative profile in late August, after two weeks decline, can be attributed to precipitation. A nearby weather station recorded 2.5 inches of precipitation between August 15 and 31. According to a CCAD soil moisture model (Crop Moisture Index - Exhibit 1,C) this precipitation was sufficient to partially recharge the subsurface soil profile thereby temporarily stopping the normal decline of the natural vegetative profile. The same model indicated that late July precipitation was not sufficient to recharge the subsurface soil profile and that the soils continued to dry.

Figure 18 shows Segment 1636 during the growing season. The natural vegetative profile in August increased slightly due to 2.2 inches of precipitation between August 15 and 31. The small grain profile increased during the same time period when it should have declined due to maturity. Further investigation revealed that the profile increase was not due to rejuventation but was due to the AVI calculation criteria. The formula used to calculate the AVI was described in Section 2.1, Vegetative Indices. The average AVI is a product of all pixels with positive AVI values. Negative values do not enter into the calculation. Due to maturing the number of pixels involved in the September 1 small grain index is fewer than was involved in the August 14 small grain index. Although fewer pixels were involved on September 1, their individual AVI values were higher and, therefore, raised the average AVI value for the small grain profile.

FIGURE 17

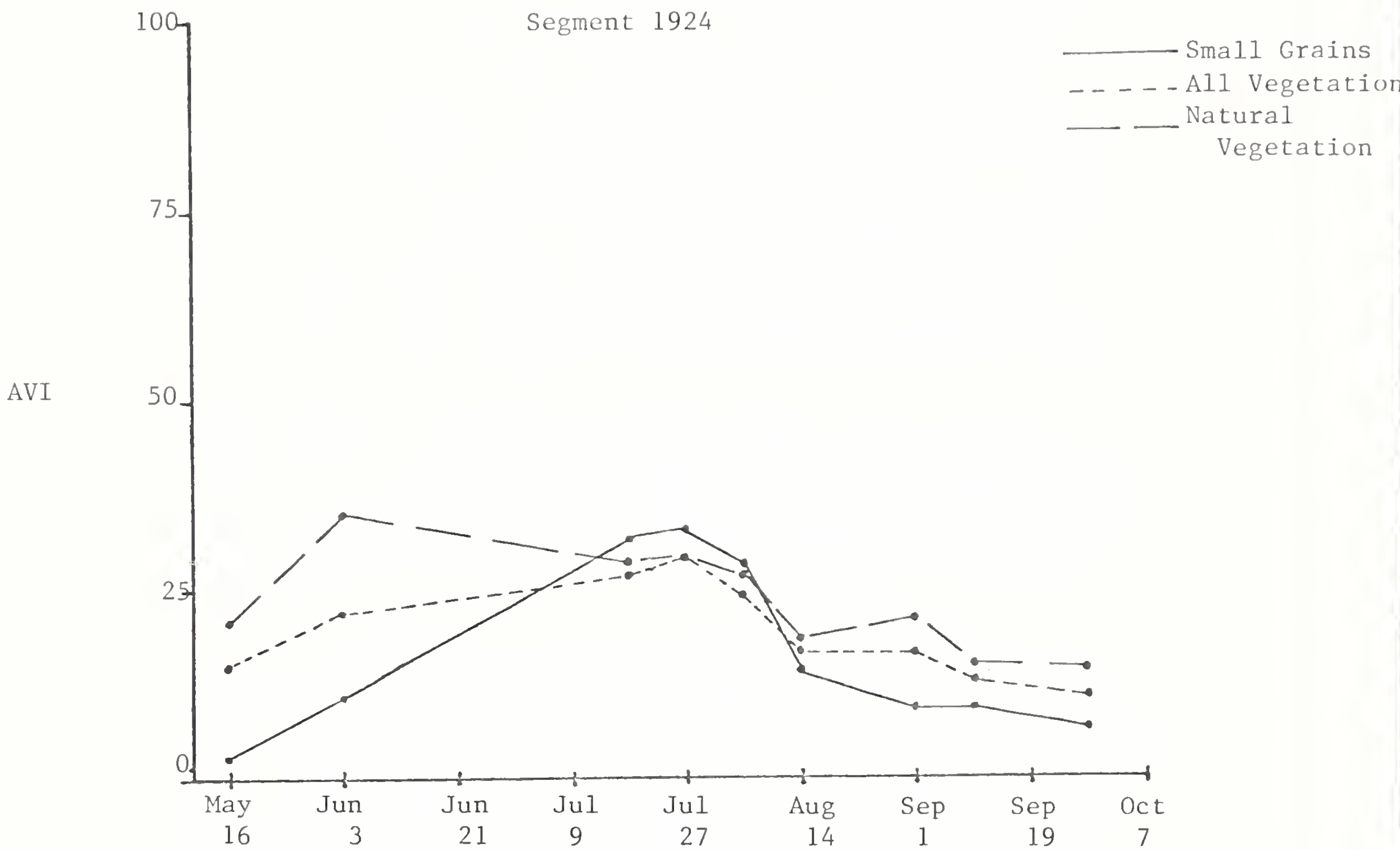


FIGURE 18

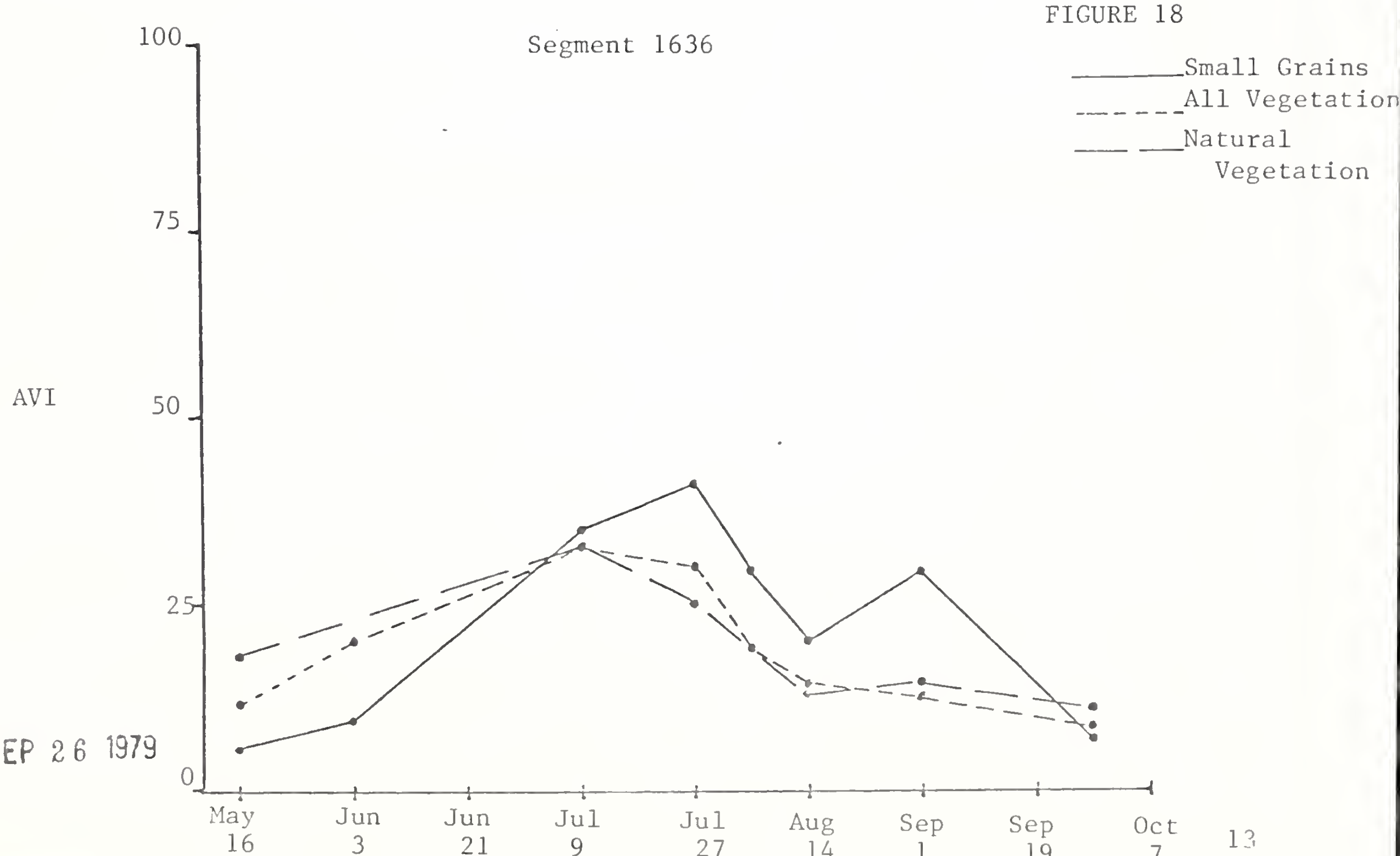


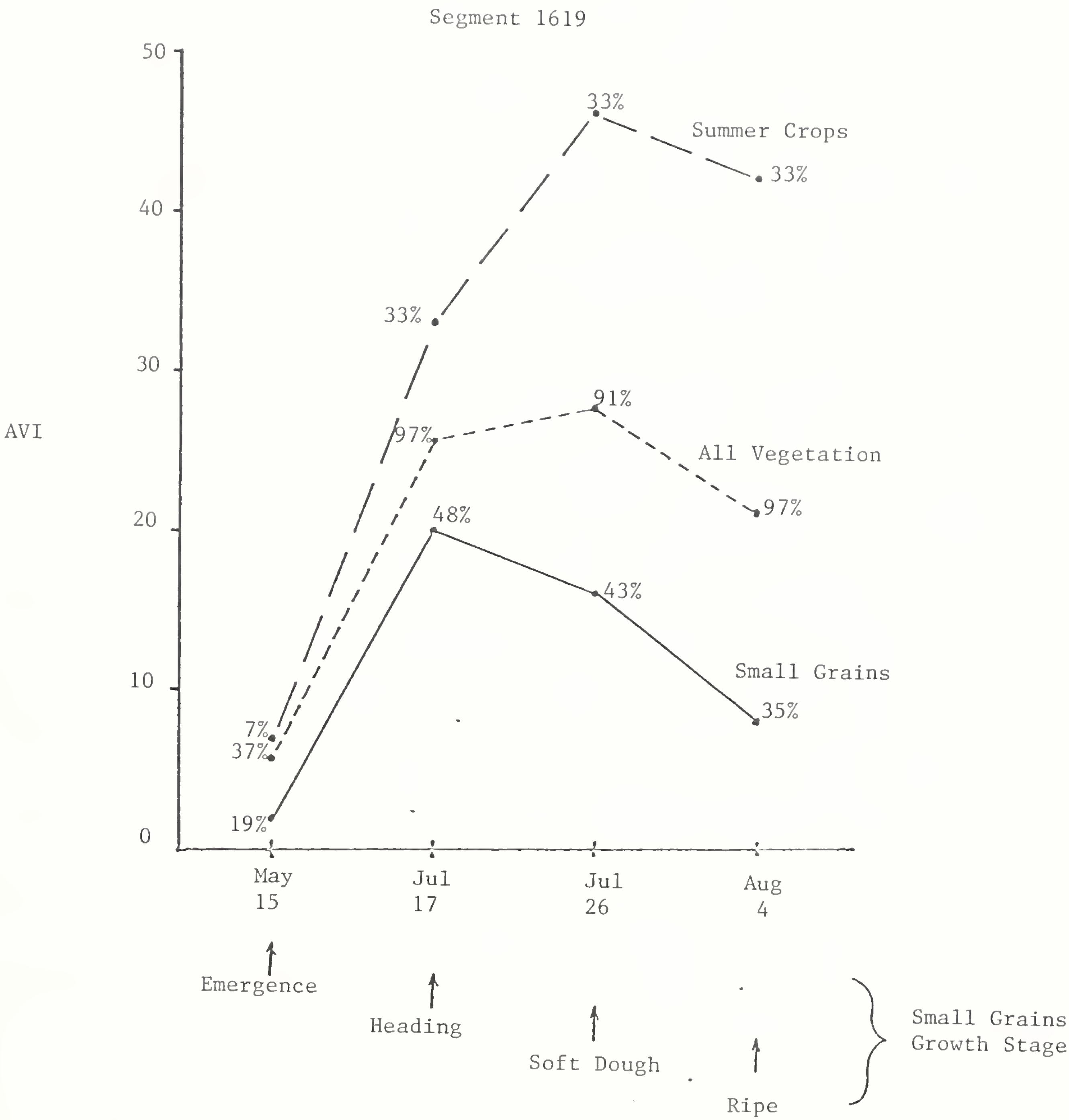
Figure 19 presents a situation where the AVI representing all vegetation (unsupervised) increased as the small grain crop matured. Between July 17 (heading) and July 26 (soft dough) the all-vegetative profile increased even though the crop was maturing. The number of pixels involved in the calculation declined from 97 to 91 percent. The reason is shown by the small grain and summer crop plotted profiles. The small grain profile and the percent pixels involved in the calculation declined between July 17 and July 26. The summer crop profile increased dramatically between the same dates; and since the profile representing all vegetation is unsupervised, the overall AVI value increased. The problem is minimized in mono-cropped areas but can present significant index interpretation problems in multicropped areas.

2.1.4 Relationships of Indices to Baseline Data. As is apparent in the previous text, significant problems exist in interpreting both unsupervised and supervised indices relative to crop condition during a single year. The following examples show how indices can be interpreted against baseline index data representing a previous year.

Figure 20 represents the numerical difference and percentage difference (in parentheses) of unsupervised AVI values for July 7-12, 1978, over July 12-17, 1977. The comparative calendar dates were slightly different due to the difference in satellite orbits between years. Even though 1978 coverage is five days earlier than 1977 coverage, the indices indicate that 1978 is greener than 1977. The time period of this comparison is at heading for the 1978 wheat crop and should give more accurate crop condition results than at any other time of the crop year. A previous study indicates that individual field indices relate to final yield better at heading than at any other time during the growing season (Exhibit 1, B). An initial assessment would indicate that the entire state, except for one segment value, was in better condition than in 1977.

To provide a tool to evaluate the above assessments, a map (Figure 22) showing yield differences of 1978 over 1977 was developed. The map isolines SRS county yield differences at 5 bushel intervals. Positive isolines show areas that were better in 1978 than in 1977 while negative isolines show areas that were worse. The one negative value in Figure 20 corresponds with the negative area in the northern part of the state. The southeastern part of the state, as shown by Figure 22, was not as good in 1978 as in 1977, but the indices in Figure 20 did not indicate it was in better condition. Extremely high differences (numerical and percentage) in the southwestern and central parts of the state seem to relate quite well to the 10 bushel increase in 1978.

FIGURE 19



Segment 1619
AVI
50
40
30
20
10
0
33%
Summer Crops
33%
33%
91%
97%
All Vegetation
97%
48%
43%
Small Grains
35%
7%
37%
19%
May 15
Jul 17
Jul 26
Aug 4
Emergence
Heading
Soft Dough
Ripe
Small Grains Growth Stage

FIGURE 20
Difference of
July 7-12, 1978
over
July 12-17, 1977

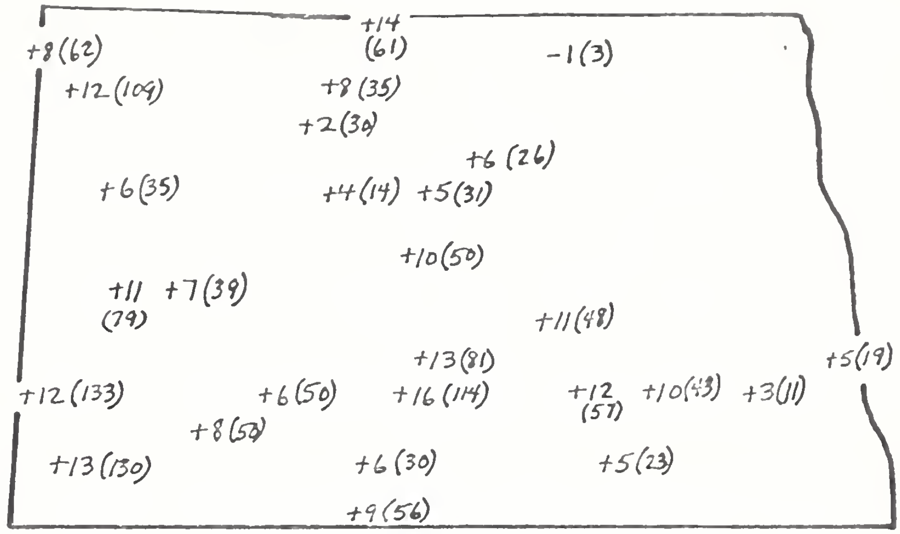


FIGURE 21
Difference of
July 7-12, 1978
over
June 24-29, 1977

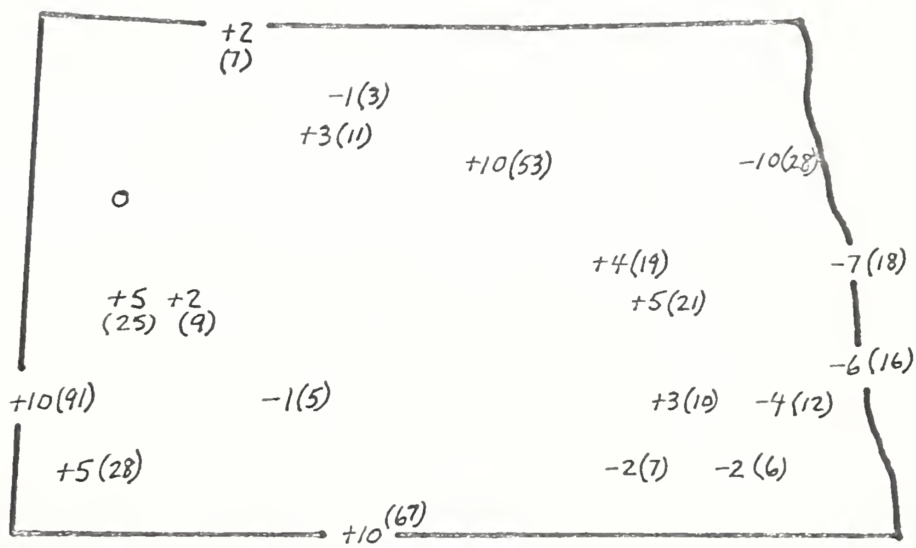
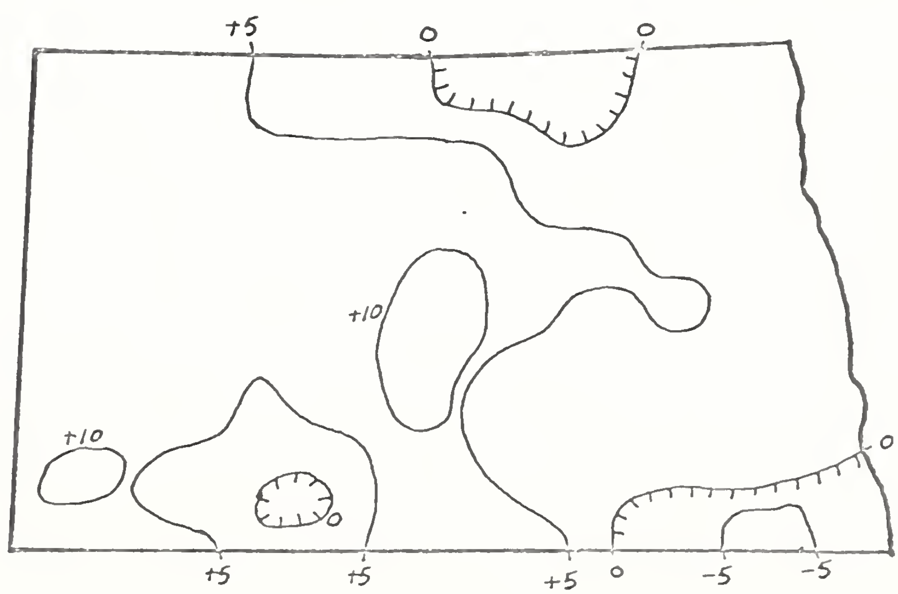


FIGURE 22
Wheat Yield (bu)
Difference of
1978 over 1977



Further investigation revealed that the 1978 crop was 10-14 days behind the 1977 crop. Knowing that comparisons should be at the same growth stage, different 1977 coverage was used to compensate for the growth stage differences between the two years. Figure 21 shows the differenced values of July 7-12, 1978, over June 24-29, 1977. The 1978 data are 13 days later, rather than 5 days earlier as in Figure 20, than 1977 data and is at approximately the same wheat growth stage. This new comparison reveals that the south-eastern corner of the state was generally not as good in 1978 as in 1977. Other negative values on Figure 21, are not necessarily in negative areas on Figure 22, but seem to be in the same general location of areas that were worse in 1978 than in 1977.

The same comparisons were done using GIN plots (Figures 23 and 24) with similar results obtained. Like the AVI, extremely high differences in the southwestern and central parts of the state show much better conditions in 1978 than in 1977. However, the extreme sensitivity of the GIN to pixels moving back and forth across the threshold value of 15 (see Sections 2.1 and 2.1.3.1) seems to create problems with comparing data between years. A GIN value of +64 (640 percent) on Figure 24 in the northern part of the state indicates that the GIN was 64 counts or 640 percent higher than in 1977. The actual 1977 and 1978 GIN values were 0 and 64, respectively. The AVI showed an increase of +2 or 7 percent for the same comparison. Postive and negative GIN values do not line up as well as the AVI values with the map showing yield differences between the years.

FIGURE 23

Difference of
July 7-12, 1978
over
July 12-17, 1977

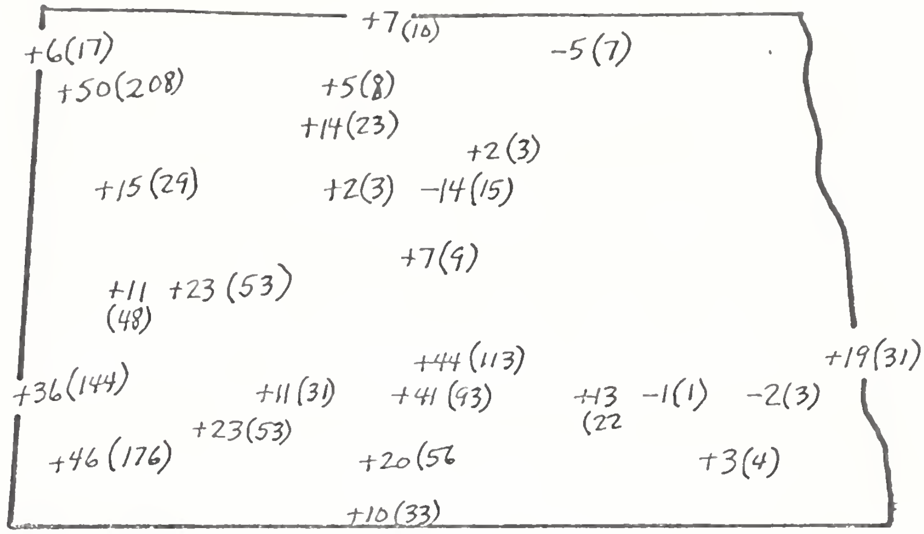


FIGURE 24

Difference of
July 7-12, 1978
over
June 24-29, 1977

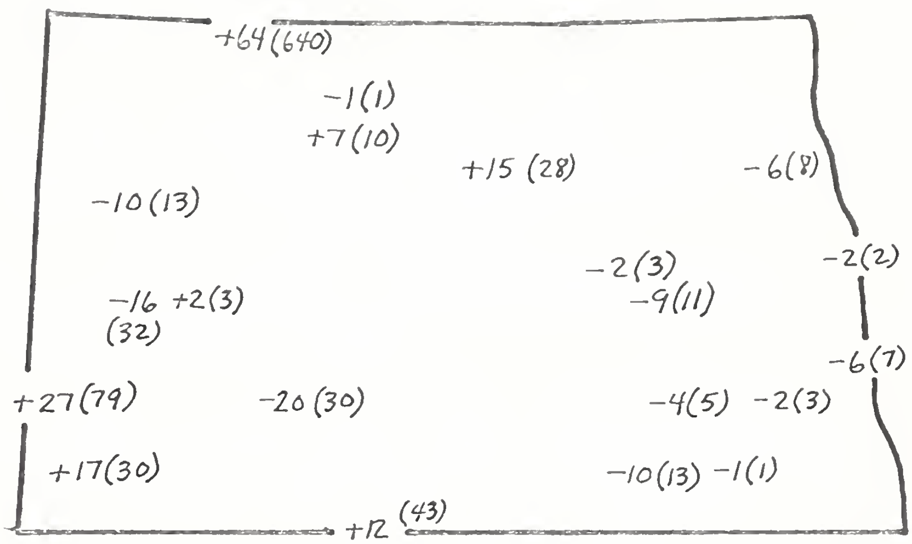
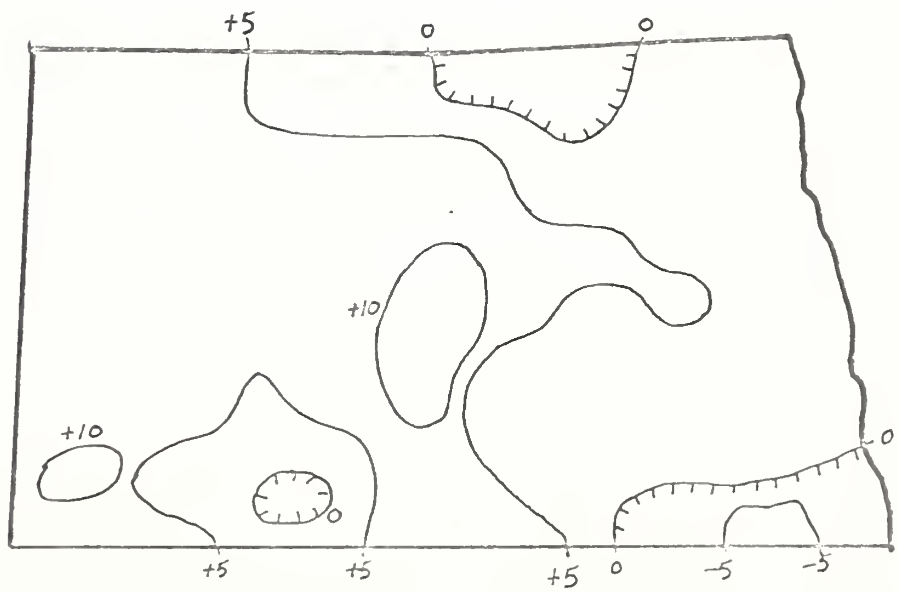


FIGURE 25

Wheat Yield (bu)
Difference of
1978 over 1977



PART 3.0 CONCLUSIONS AND RECOMMENDATIONS

3.1 CONCLUSIONS

- Unsupervised index values representing all growing vegetation are difficult to interpret since each value relates to a unique segment.
- Since segments are individually unique, isoline maps of indices containing all vegetation do not relate well to crop condition and may be easily misinterpreted. Indices having the same value are not equal and do not necessarily reflect similar crop conditions.
- The use of index values relating to all vegetation to assess the condition of a particular crop is difficult since extraneous vegetation distorts or moderates, according to population, the unsupervised index value.
- Unsupervised vegetative indices do not relate well to wheat growth stages in areas with considerable competing vegetation (natural vegetation or summer crops).
- If each segment across a geographic area contained the same crop mix and the same amount of agriculture, then unsupervised index values could easily be interpreted. However, since they are not of the same composition, supervised techniques relating to specific crops are needed to improve interpretations.
- Supervised index values relating to specific crops can be distorted by applying a threshold value to screen out pixels of that crop falling below a certain threshold.
- Assessment of unsupervised indices should be interpreted against baseline indices from a previous year. This can best be done by assessing index differences between the current and baseline years. Differenced values show some promise for isoline displays.
- Comparisons of indices between years can be improved by shifting for crop calendar differences between the years. This shift is more meaningful when assessing crop specific indices (supervised) since each type of vegetation cannot be shifted separately for assessment of unsupervised indices.
- GIN does not measure enough levels of vegetative biomass intensity for quantification of crop condition.
- Both AVI and GIN unsupervised indices are subject to distortion resulting from different vegetative types moving back and forth across the index threshold. The index threshold for the AVI and GIN are 0 and 15, respectively.
- Precipitation slows the normal vegetative decline of natural vegetation during the summer. Indices may increase slightly but usually level-off.

3.2 RECOMMENDATIONS

- Cautiously use information derived from unsupervised indices, whether it is individual numerical values or isoline maps.

- Techniques should be developed to automate the comparisons of indices against baseline years (differences), to adjust for comparisons according to growth stages between years, and to compensate or interpolate for missing index data.

- Although not assessed in this report, sun angle and haze corrections of Landsat data prior to index calculations should make comparisons and assessments of crop conditions among geographic areas and between calendar dates more accurate.

- Crop calendar shifts should be accomplished at the level for which an index represents (segment/cell) rather than at the orbit level. The assumption cannot be made that growth stage relationships across a large geographic area are similar between comparative years and can be shifted altogether.

- As man-power allows, emphasis should be placed on supervised index techniques since this allows for two types of assessment - within and between years across a geographic area.

- When calculating crop specific indices, threshold values to reject pixels below a certain index value should not be used.

EXHIBIT I

REFERENCES

A. Aaronson, A., Davis, L., and May, G., "Results of the Vegetative Index Correlation Study", 6-TM (February 9, 1979), The Crop Condition Assessment Division - FAS/USDA

B. Aaronson, A., and Davis, L., "An Evaluation of Relationships between Vegetative Indices, Soil Moisture and Wheat Yields", 9-TM (to be published), The Crop Condition Assessment Division - FAS/USDA.

C. Palmer, W.C., "Meteorological Drought", Weather Bureau Research Paper No. 45, 1965.

APPENDIX A

VEGETATIVE INDICES

GIN - Green Index Number

AVI - Ashburn Vegetative Index

DVI - Difference Vegetative Index

GVI - Green Vegetative Index

KVI - Kauth Vegetative Index

LAI - Leaf Area Index

PVI - Perpendicular Vegetative Index

TVI - Transformed Vegetative Index